PSEUDOBRECCIATION IN ORDOVICIAN LIMESTONES IN MANITOBA

R. C. WALLACE
University of Manitoba, Winnipeg

THE ORDOVICIAN IN MANITOBA

The Ordovician in Manitoba, as determined by Dowling,[1] consists of the following series in ascending order: (1) The Winnipeg sandstones, directly overlying the eroded surface of the pre-Cambrian. This division consists of beds of soft, often very white, friable sandstones, about 100 ft. thick, containing only a few fossils. The St. Peter sandstone of Minnesota is similar in petrological aspect, but the absence of true Chazy fossils in the Winnipeg sandstone procludes definite correlation with the St. Peter sandstone. The fossils rather suggest upper beds of the Black River, but this formation is in Minnesota represented by shales. (2) The Lower Mottled limestone, exposed along the west side of Lake Winnipeg, and on some of the islands. This formation is about 70 ft. thick. The character of the limestone is very similar to that to be described in detail as the Upper Mottled limestone. It is mottled buff and greyish white, is highly fossiliferous, and shows what are probably fucoidal tracings on the bedding planes. The upper beds are highly charged with siliceous material. (3) The Cat Head limestone, yellow dolomites, even grained and as a rule fine grained, containing cherty concretions which in many instances exceed a foot in diameter. The beds have been estimated to be 68 ft. thick. The large cephalopods which are so common in the Lower Mottled are wanting in the Cat Head series. (4) The Upper Mottled limestone, exposed at several points on the western shores of the northern extension of Lake Winnipeg; also along the Red River, and at the time of Dowling's work more particularly at East Selkirk. Today the limestone quarries of Tyndall provide very good sections of this limestone. The thick-

[1] Geological Survey of Canada, *Annual Report*, 1900.

ness of the division is about 130 ft. Like the Lower Mottled, this limestone is highly fossiliferous, and is characterized by the presence of fossils of large dimensions: various orthoceratites, *Maclurea manitobensis* and *Receptaculites oweni* are particularly abundant. The mottled character of the stone will be subsequently described in detail. The chief difference that has been noted between this and the Lower Mottled is that frequently the pale-colored areas of the Upper Mottled are chalky in character, and readily soil the fingers, a feature not observed in the Lower Mottled. (5) The Stony Mountain formation, a series of ochreous shales overlaid by massive dolomitized limestones, showing a maximum thickness for the whole series of 110 ft. The beds thin out northward. The shales at the base are highly fossiliferous, and probably represent the Utica shales of the Cincinnati group. The top beds of the Ordovician in Manitoba are overlaid, presumably conformably, by the thin-bedded, dolomited limestone of the Niagara formation, exposed at Stonewall and at the mouth of the Saskatchewan River.

Further detailed work is required before an exact correlation of these beds with the Ordovician of Minnesota, Wisconsin, and Iowa can be given. Pending this, the following alternative correlation is submitted, the latter of which seems with the present evidence the more probable.

Minnesota, Wisconsin, and Iowa		Manitoba	Minnesota, Wisconsin, and Iowa
Maquoketa shale		Stony Mountain form (190 ft.)	Maquoketa shale
Galena dolomite	Trenton	Upper Mottled limestone (130 ft.) Cat Head limestone (70 ft.) Lower Mottled limestone (70 ft.)	Galena dolomite Green shales (Black River) Plattville limestone
Green shales (Black River)		Winnipeg sandstone (100 ft.)	St. Peter sandstone
Plattville limestone St. Peter sandstone			

THE MOTTLING OF THE LIMESTONE

The quarries at Tyndall furnish good exposures of the Upper Mottled limestone. The following description applies more particularly to what was formerly known as Garson's quarry, now under

the management of the Northwest Quarries Co. Ltd. The surface capping of drift is 8–10 ft. thick, and the bowlders are mainly limestone, very few Archaean granites or gneisses being found. Underlying the drift are thinly and irregularly bedded limestones, 3 ft. thick, mottled in similar fashion to the more massive limestones underneath. Then follow 14 ft. of buff mottled limestone, wrought in ledges 3–6 ft. thick (Fig. 1). This is practically homogeneous,

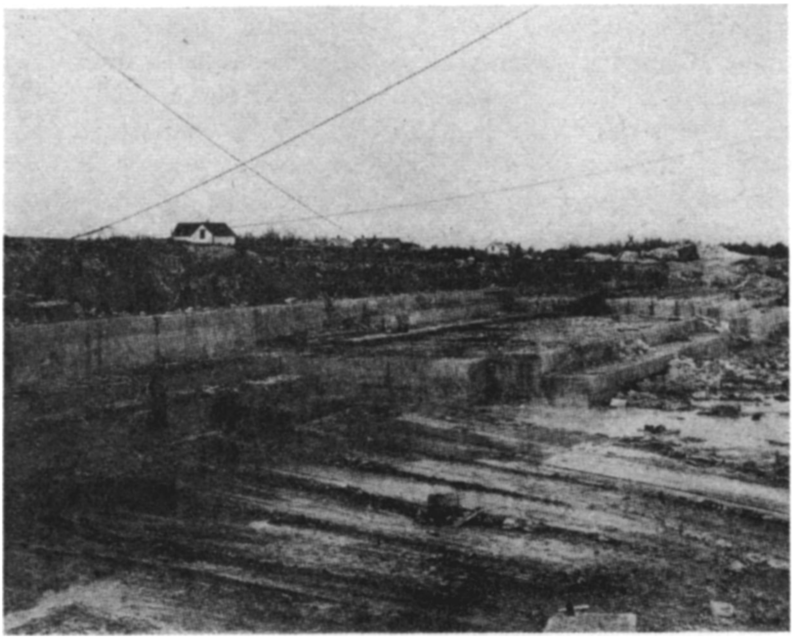

FIG. 1.—Upper Mottled limestone, Garson's Quarry. Tyndall

though certain horizons show the presence of cephalopods more markedly than others (see Fig. 2). Underneath is a blue mottled limestone, uncovered for 6 ft., the darker patches on the stone showing, even on the weathered surface, a darker blue color than on the buff stone. A bore has recently been sunk in order to determine the quality of the underlying strata, and the manager of the quarry, Mr. Pfeiffer, has kindly supplied the following details. The blue mottled is altogether about 13 ft. thick. Underneath this lies a second horizon of buff mottled stone. The quarry and

bore together expose 97 ft. of stone, the lower 62 ft. of which is buff, and so thinly bedded as to be valueless as a dimension stone. In this is found, at a depth of 51 ft. below the top of the limestone in this exposure, a bed 16 ft. thick which might be described as a very impure limestone, high in argillaceous material.

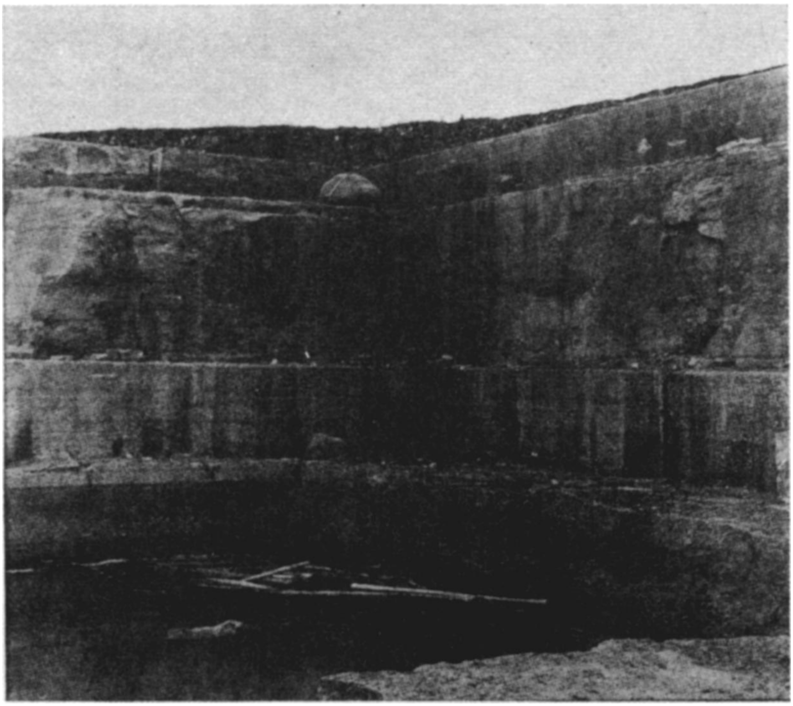

FIG. 2.—Upper Mottled limestone, Henry's Quarry. Tyndall

The rock consists of a light-grey limestone, with patches of darker material scattered through the stone. Though these darker areas are distributed apparently quite irregularly, slabs cut parallel and perpendicular to the bedding planes show that the linear extension of the patches is decidedly along the bedding planes. A comparison of the side of the slab shown in Fig. 3 (cut along the bedding plane) with its end section will be convincing. There is no evidence, on the other hand, of greater development of the darker areas along jointing planes than in any other vertical direc-

tion. The patches, when seen along the bedding planes, have a certain linear development, suggesting branching structures rather than concretionary arrangements. Vertical sections are, however, more commonly roughly circular. The cross-sections are usually not more than 1½ in. in diameter, while along the bedding planes irregularly extended areas 5–6 in. in length are not uncommon.

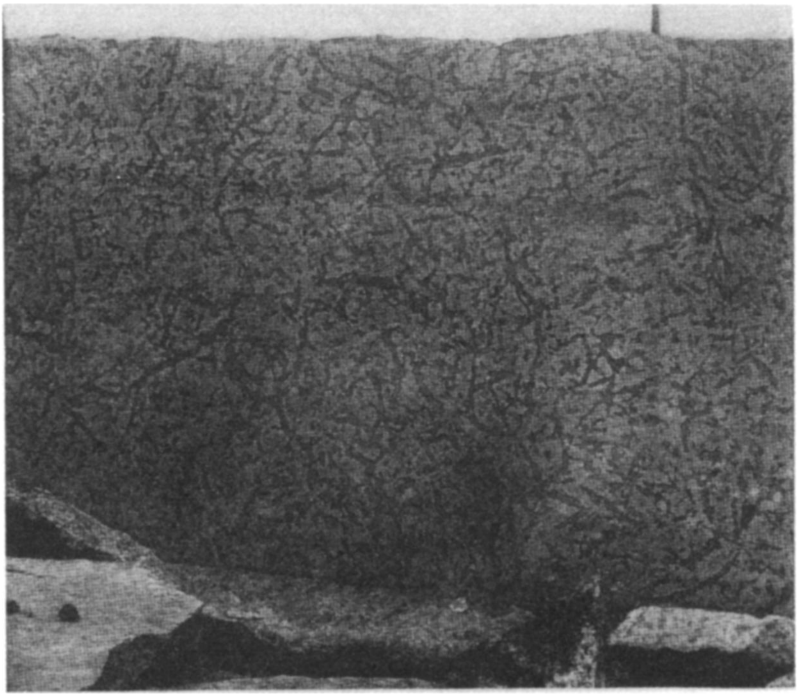

FIG. 3.—Slab of limestone, cut parallel to bedding plane

What are apparently fucoidal traces have been noted on the bedding planes of both the Upper and Lower Mottled limestone. This may have suggested the only explanation that has been offered as to the origin of the mottling of the stone in this district—that given by Panton:[1]

> It [the limestone at East Selkirk] presents a peculiar mottled-like appearance, which adds much to its beauty as an ornamental stone. This strange mixture of brown and white is difficult to account for. In some cases it appears

[1] *Trans. 15 Man. Hist. and Scient. Soc.*, Winnipeg, 1884.

as if the origin might be due to seaweed remains. Often the colored portion approaches the color of yellow ochre, and seems strongly impregnated with iron, while the intervening spaces are more or less colored.

Later work on the Galena and Trenton of Iowa by Leonard[1] has shown that the Galena, which is considered to be a dolomitized phase of the Trenton, is found to grade into the underlying Trenton through strata which possess a somewhat similar mottled appearance to those already described. An analysis showed that the darker areas were dolomitized, while the lighter were unaffected by the magnesia-bearing waters. This was inferred from the chemical analyses for $MgCO_3$ and $CaCO_3$ which were as follows: grey portion, 97.46 per cent $CaCo_3$, 4.31 per cent $MgCO_3$; buff portion, 60.97 per cent $CaCO_3$, 18.28 per cent $MgCO_3$ (*op. cit.*, p. 259). It was also suggested that jointing planes and the spaces between the larger fossils and the surrounding limestone might have served as chambers of passage for the waters which effected the dolomitization. It was observed that although the fossils were not themselves affected, they were frequently surrounded by a dolomitized area.

Under the microscope the difference in structure between the two areas is very apparent (Fig. 5). The darker-colored patches are evenly crystallized, showing sections of rhombohedra of dolomite, set close together, and occasional crystals of hematite passing over into limonite. The color is due to the hematite and, more particularly, the limonite, to which the action of percolating water has imparted a banded structure. Excepting a few large shells, which have not been affected, there are no traces of organic remains in the dolomitized areas (see Fig. 4). The light-colored areas, on the other hand, contain numerous fragments of brachiopod shells, with occasional sections of polyzoa and corals. These are set in a fine-grained calcitic material, strikingly different, even at the margin between the two areas, from the fairly perfectly crystallized dolomite. No hematite or limonite occurs in the lighter material except where occasional local dolomitization has taken place, and there the rhombohedra are always colored by the iron ore. That this is actually a case of pseudobrecciation, and not a

[1] "Geology of Clayton County," *Iowa Geological Survey*, XVI, 259.

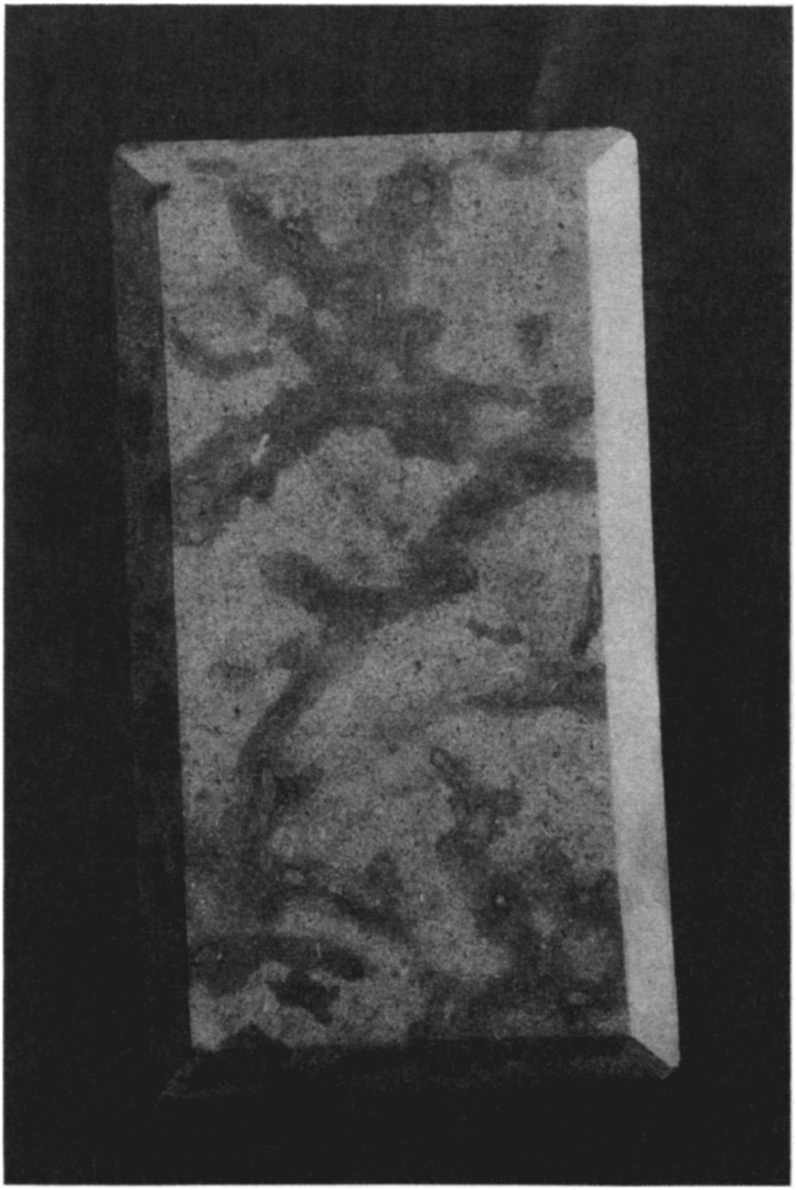

FIG. 4.—Polished surface of the limestone

brecciated structure due to the cementation of a dolomite breccia in a calcareous matrix, is evident from the microscopical examina-

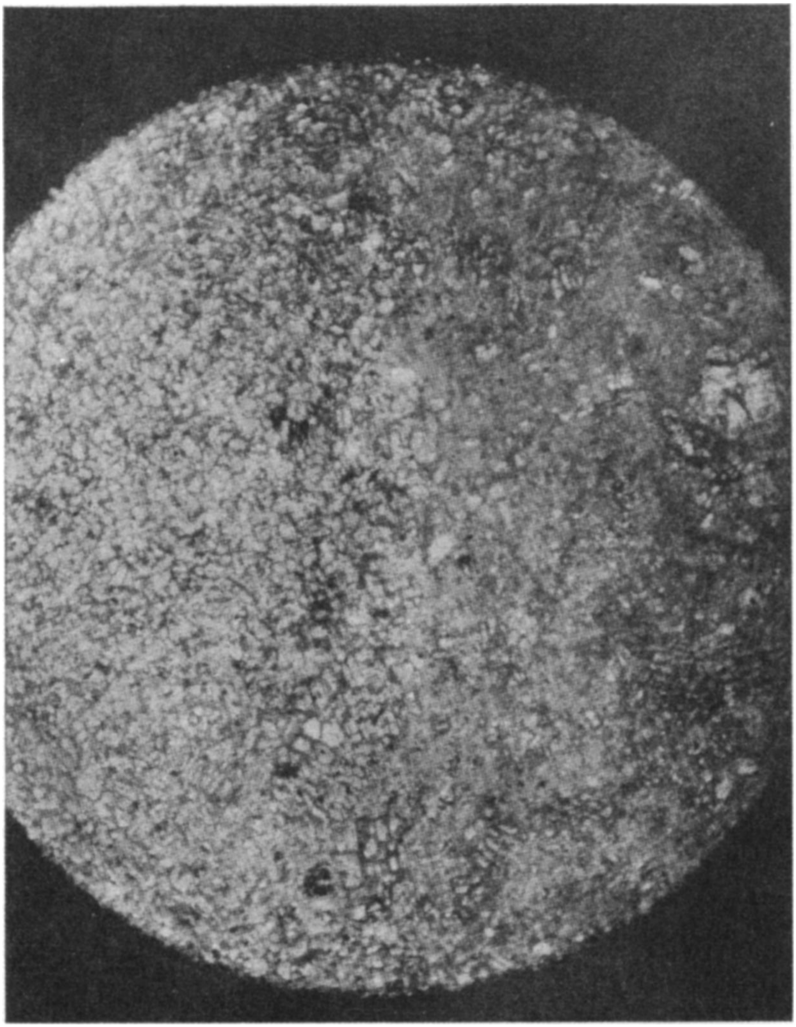

FIG. 5.—Thin section, showing margin between dolomitized (left) and undolomitized (right) limestone. ×31.

tion. In several thin sections there are found at the margins of the dolomitized areas fossils which have been surrounded by a thin

strip of dolomitic material—the dolomitization having ceased when the percolating waters met round the shell. That breccia of such a type could have existed without the fossils becoming detached is hardly possible. A study of the margin of the darker areas leaves no doubt that we are dealing with a secondary dolomitization. Although there is a definite marginal line, it shows so sharp interpenetration of dolomitized and undolomitized material that it could have been caused only by the irregular advance of waters bearing magnesian salts in solution.

Microscopic investigation shows that the hematite, which with the limonite is responsible for the color effect of the darker patches, is found in crystals separate from the dolomite, and at the edges of the dolomite rhombohedra. The dolomite is itself clear and colorless; and the position of the hematite crystals, and their invariable association with dolomitic areas suggest naturally that the hematite was formed by the same agency that gave rise to the dolomitization. From the microscopic evidence alone, the most feasible explanation seemed to be that during the process of dolomitization the ferruginous material, originally present in the form of ferrous carbonate as an isomorphous admixture with the calcitic material, had to a large extent separated out owing to the greater inability of the dolomite to hold the iron isomorphously. Once separated as carbonate, the iron would undergo oxidation much more rapidly than is possible in a mixed crystal where the calcite exercises a controlling influence, retaining the iron in the ferrous state. A chemical analysis should then show—if this theory can be supported—that although the darker areas are richer in magnesia and in ferric iron, and the lighter areas contain practically no magnesia, the total iron is approximately the same in both.

CHEMICAL INVESTIGATION

The two varieties were separated as completely as possible, and subjected to chemical analysis. The calcium was estimated volumetrically, the magnesium gravimetrically. The total iron is given here as Fe_2O_3. The iron precipitate was dissolved and reduced by zinc, and the iron estimated volumetrically. The ferrous iron was estimated volumetrically in a separate portion.

The following may be taken as representative of several sets of analyses.

	Light Colored	Dark Colored
SiO_2	1.56 per cent	1.56 per cent
Total iron, as Fe_2O_3	0.16	1.94
(FeO	0.12	0.45)
Al_2O_3	0.06	2.27
$CaCO_3$	94.02	71.03
$MgCO_3$	4.33	23.35
Total	100.13	100.15

The analyses show that nearly all the iron and alumina have been introduced with the Mg-bearing waters. The theory outlined above is consequently untenable. It may also be pointed out here that while in the light-colored limestone, where the ratio of the $MgCO_3$ to $CaCO_3$ is approximately 1:22, no recrystallization has taken place, in the darker stone, where the proportion is roughly 1:3, "dolomitization" has taken place, though the proportion required in a true dolomite is 1:1. This point will be again referred to in the discussion of the origin of the "dolomitization."

THE ORIGIN OF THE MOTTLING

If we exclude true brecciation as an explanation of the mottled effect of these limestones, there remains only one or other of two possibilities. Either the dolomitization has taken place practically simultaneously with the formation of the limestone, or subsequent dolomitization has ensued by water infiltration after a great thickness of the limestone has been laid down, and consolidation has taken place. Dixon, who has made a study of the dolomitization of the Carboniferous limestone of South Wales,[1] remarks on the difference between contemporaneous and subsequent dolomitization. He considers that subsequent or vein dolomitization is characterized by (*a*) larger average size and greater clearness of the rhombohedra, (*b*) inclusions of hematite, (*c*) association of dolomitization with calcification, (*d*) preference of dolomitization

[1] *Quart. Jour. Geol. Soc.*, XVII (1911), 477; and *Geology of South Wales Coalfields*, VIII (1907), 15 ("Memoirs Geol. Survey").

for oöliths and corals. In the case of vein dolomitization, calcification usually precedes dolomitization, the softer, abraded material being first attacked by water and recrystallized, while the Mg-bearing waters subsequently attack what has not been affected. Thus the parts that are affected by the Mg-bearing waters in subsequent dolomitization are just such as contemporaneous dolomitization would not affect—oöliths, corals, etc., the hardest parts in ordinary sediments but the softest in the recalcified rock. Judged by Dixon's tests, the pseudobrecciation of the Manitoba limestones is contemporaneous. There is no secondary calcification, the harder shells of corals, brachiopods, etc., have not been attacked in preference to the matrix, and the hematite is not included in the dolomite crystals. It seems difficult to imagine how subsequent dolomitization could affect a limestone in such a way that throughout a thickness of almost a hundred feet a uniform mottling should be produced, the affected areas being unconnected vertically. Leonard[1] seems to favor the view that the dolomitization in Clayton County is a subsequent phenomenon, in the sense that it was probably contemporaneous with the dolomitization of the Galena. This was inferred from the fact that the mottled limestones were found separating the fully dolomitized Galena from the underlying undolomitized Trenton in all cases except where impervious shales formed a sharp boundary line between the uniformly dolomitized and the non-dolomitized strata. The actual conditions are, however, different in Manitoba. Both the Lower Mottled and Upper Mottled limestones are overlaid by more completely dolomitized horizons—the Cat Head and the Stony Mountain formations—but a gradation from a mottled stone to a grey undolomitized limestone has nowhere been observed; nor can it be said that there is in any measure a gradation from a sparingly dolomitized variety by regular stages into a typical dolomite. The proportion of darker material is as great at the base of a section of mottled limestone 97 ft. thick as it is at the top.

CONTEMPORANEOUS DOLOMITIZATION

The evidence goes to show that the dolomitization in this area took place more probably as a practically contemporaneous

[1] *Loc. cit.*

phenomenon when the calcareous mud was as yet only partially solidified. We have then to account for the selective dolomitization of the calcareous ooze. Dolomite is formed according to the following reversible reaction:

$$2CaCO_3 + MgCl_2 = CaCO_3 \cdot MgCO_3 + CaCl_2$$

and the action is found to proceed from left to right when a temperature of 100° C. is reached. Increase of temperature accelerates the action. It is well known, however, that dolomitization has taken place, and is taking place today, where the proportion of Mg salt to Ca salt is much below that represented by the above equation. The process that goes on in nature is perhaps more accurately represented, as Klement has suggested,[1] by a continuous readjustment of equilibrium between the solution pressure of the solid $CaCO_3$ and the pressure of the Mg ions out of solution. Dolomitization would then ensue after the $CaCO_3$ had been precipitated; or, more correctly, a transformation takes place by which crystals of the optical characters of dolomite are formed, though the percentage of $MgCO_3$ may be smaller than that required for a true dolomite. In other words, dolomite is seemingly capable of forming mixed crystals—up to a certain limit—with $MgCO_3$, a substance not strictly isomorphous with itself. If then the reaction be stated crudely as $Mg'' \leftrightarrows Ca$, as an abbreviation for the statement that the two reactions $Mg'' \leftrightarrows Mg$ and $Ca \leftrightarrows Ca''$ are not independent, but regulate each other, three factors would affect the equilibrium: (1) percentage of Mg'' in the sea water, (2) temperature of the water, (3) character, though not of course the quantity, of the $CaCO_3$. An increase of Mg ions, and increase of temperature move the equilibrium point from left to right; while $CaCO_3$ in the form of aragonite is more readily affected, especially at moderately high temperatures, than is calcite, presumably because of the greater solution pressure of the $CaCO_3$ in the aragonite modification. In seeking for an explanation of selective dolomitization in the Manitoba limestones, one may practically discard the second and third factors. Local temperature changes may be neglected, except in so far as taken into account in a hypothesis outlined below, and there is no indication that aragonite shells have been attacked.

[1] *Tscherm. Min. Petr. Mitteil.*, XIV (1895), 530.

The proportion of Mg salts in ordinary sea water is very small (0.12–0.15 per cent Mg, increasing slightly with the depth). In inland seas, exposed to excessive evaporation, it may rise to 4.15 per cent Mg, as in the Dead Sea at 300 meters depth. Such exceptional conditions could not have prevailed; indications point to a clear, rather shallow sea, with recurrent periods of slight sedimentation. It may well be, however, as indicated by Steidtmann,[1] that the seas of the early Palaeozoic contained a slightly greater proportion of Mg salts than do similarly situated seas of today. The proportion of $MgCO_3$ in the paler-colored limestones shown by the analyses represents the amount of $MgCO_3$ that was deposited under normal conditions in these seas. It may be taken as the solid phase in equilibrium with the Ca and Mg salts in solution at that particular temperature and pressure, though undoubtedly a small proportion of the $MgCO_3$ was originally introduced as an ingredient in the composition of the calcareous shells. No recrystallization, and consequently no dolomitization in the strict sense of the word, has taken place. Presumably the $MgCO_3$ exists in solid solution with the very fine-grained calcitic material in which the broken shells are imbedded.

It would appear, then, that the dolomitization (with recrystallization) of the darker areas was due to the presence locally of a larger percentage of Mg salts than the normal. From this point of view three suggestions as to the cause of the dolomitization might be examined: (1) that algae, either as attached fucoids or as unicellular algae of the plankton, had contributed the necessary salts; (2) that the markings are due to worm castings; (3) that sea water inclosed in cavities, such as the interiors of shells, had dolomitized the neighboring rock.

The last of these suggestions we may consider first. Occasionally large shells are found in the center of the dolomitized areas, while no other trace of organic remains is to be found. If sea water replaced the softer parts of the organisms on their dissolution, and was retained till the layers were buried under a gradually hardening oöze, the slight rise in temperature and pressure might be sufficient, where undisturbed contact between the solid and

[1] *Jour. Geol.*, XIX (1911), 323.

liquid phases was preserved over a long period, to effect a gradual dolomitization. A concentration of magnesium salts in such a case is hardly possible, as evaporation could not have taken place; the result must be attributed entirely to long-continued favorable physical conditions. This is the explanation that first suggested itself; but it is hardly tenable. If such a process does actually take place, it is difficult to see why it should be the exception rather than the rule, as the possibility of inclusion of sea water in fossiliferous limestone, owing to the decomposition of the softer parts of the organisms, would always be fairly great.

Tracings of *Serpulites dissolutus* and of *Arabellites* sp. undet. have been identified in the limestones of the Lower Mottled division. It might naturally be suggested that the mottled effect in the limestones is due to actual castings of annelids, or to subsequent infillings of their borings. A well-known instance of the preservation, on a large scale, of annelid borings is that shown in the Middle and Upper Cambrian of the northwest Highlands of Scotland. In the Serpulite Grits and so-called "Fucoidal" beds, large trumpet-shaped depressions are found on the surface, which lead downward into vertical, cylindrical tube structures, much constricted in places. These are without much doubt the castings of annelids, the sudden constrictions and widenings representing the peristaltic movements of the intestines. Overlying these beds, limestones and dolomites 1,500 ft. thick are found, consisting in part of mottled beds (the "mottled" or "Leopard" stone of the Sailmohr group). Throughout the whole series fossils are rare, and the limestones, which contain numerous cherts, are attributed to the calcareous and siliceous remains of the plankton. The mottling of the limestone is due to the fact that the worm castings are dolomitized, and darker than the rest of the stone. According to Peach,[1] an explanation might be sought in the assumption either that the annelids were selective in their food, or that their gastric juices predisposed to dolomitization.

On contrasting the markings of the Upper Mottled with these, one finds two points of difference. In the limestones under discussion the markings are horizontally elongated, and irregular;

[1] Peach and Horne, and others, *The Northwest Highlands of Scotland*, p. 380.

in the Sailmohr the markings are vertical, rectilinear, and well defined. From the position and character of the markings, one may discard the theory that they are due to castings, which would in most cases be vertically disposed or grouped round definite centers. If taken simply as tracings, the difficulty in explaining the dolomitization still remains, and one is thrown back again on some such theory as the inclusion of water in the cavities left by the annelids. Although local dolomitization and mottling in limestone may in certain cases be attributed to annelids, one can hardly consider that markings of the kind found in the mottled limestones of Manitoba are due to this cause.

There remains the hypothesis that the mottling is connected with algic decomposition. Analyses due to Goedechens[1] show that the percentage of MgO in the ash of algae collected from the west coast of Scotland may reach 11.66. If then the algae of the sea bottom become buried under a thin coating of calcareous ooze before actual decomposition ensued, the liberated Mg salts might, in conjunction with the sea water of fairly high Mg content, cause such increase of Mg ions locally as to give rise to actual dolomitization. Only from such organisms and allied types could the percentage of Mg salts be increased locally to any appreciable extent. There are certain structural features of the markings that lend some support to this view of the origin of the dolomitization. They are horizontally placed, are markedly dendritic, and the sections often show a darker core which might represent the actual position of the plant; while the magnesian waters, extending outward from this central nucleus, have affected the surrounding stone. Again, thin sections of the dolomitized areas occasionally show a narrow central tube of clear, well-crystallized calcite (see Fig. 6), indicating that a cavity had existed when the dolomitization took place, and that this was subsequently infilled with calcite. Such cavities might be formed when, owing to decomposition, the organism disappeared. The hematite and limonite of the recrystallized dolomitic material would be attributed to the iron salts of the algae. Fig. 7 shows a normal cross-section, where no subsequent infilling has taken place.

[1] Pfeffer, *Pflanzenphysiologie*, I, 110.

Some of the difficulties in the way of the hypothesis may be referred to. A sea bottom in which a calcareous mud is gradually

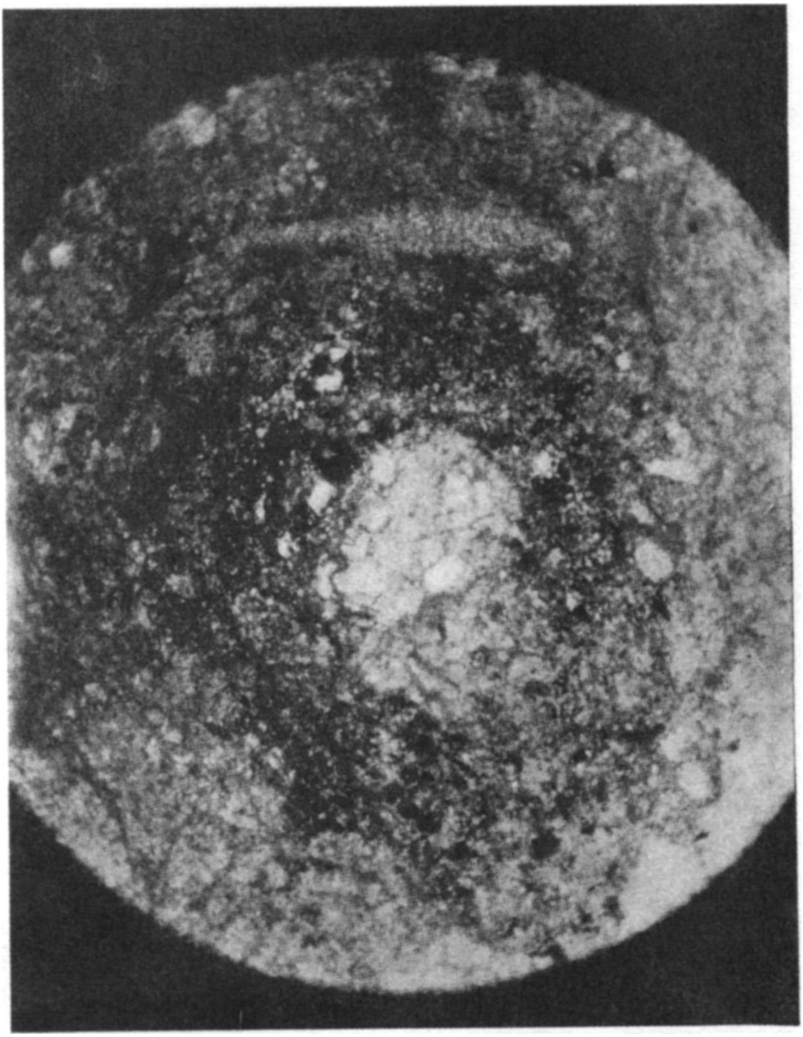

FIG. 6.—Dolomitized area with core of calcite. Border undolomitized. ×31

accumulating would not provide the rocky bottom necessary for algae in any way comparable to the laminaria of our seas; and a

profusion of vegetable growth would presumably be possible only in the shallower waters nearer shore. In the pre-Devonian rocks,

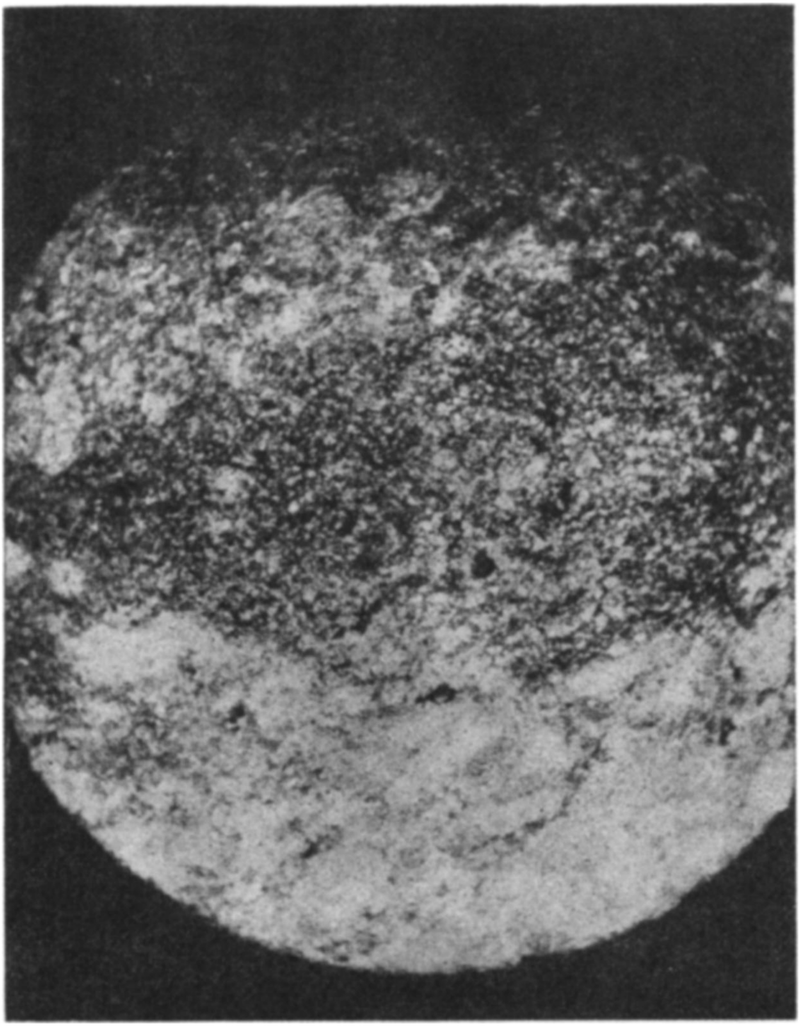

FIG. 7.—Section showing dolomitized area (center of field). ×31

definite impressions of fucoids are rare, though "fucoidal traces" have been the *dernier ressort* in cases of difficulty.[1] Unless when

[1] Seward, *Fossil Plants*, I, 139.

protected by a calcareous sheath, algae could be preserved only under exceptional conditions. We have, then, no definite knowledge of the development of attached algae in Ordovician and Silurian seas. In the strata in question, indisputable fucoids have been obtained only from the Cat Head and Stony Mountain beds, which are nowhere mottled, and are uniformly dolomitized. They are found as imperfect markings, and generally as raised impressions, and have been referred by Whiteaves to five distinct species of *Chondrites*.[1] Numerous unidentified markings on the bedding planes of the limestones have also been ascribed to fucoids.

If one may judge from the amount of carbonaceous material in rocks prior to Silurian times, it is probable that the algae had already attained a widespread development. The conditions which would give rise to dolomitization from plant forms which are so widespread in later seas must of course have been exceptional, and the chemical constitution of the seas of the period may provide the best explanation for the phenomenon. The evidence that has elsewhere been collected[2] goes to show that the percentage of magnesium salts in the early Palaeozoic seas was distinctly higher than in the ocean today. In the seas in which the Lower and Upper Mottled were laid down it was not sufficiently high to cause dolomitization in the sense that actual crystals with the optical properties of dolomite were produced; but the addition of magnesium salts from the decomposing algae was all that was required to start the process. Changing physical conditions—probably a shallowing of the sea—increased the Mg content at the time when the Cat Head and Stony Mountain formations respectively were being deposited, and in these formations a uniform, though by no means complete, dolomitization was effected. The algae may have drifted seaward from the rocky shores, and may have been fairly rapidly silted over. It is worthy of note that the presence of unicellular algae of the plankton has been confirmed in rocks of similar age in Wisconsin, and has been referred to, as already indicated, in the limestones of the upper Cambrian in the northwest Highlands of Scotland. The "oil rock" in the Galena of Wisconsin is found

[1] Geological Survey of Canada, *Palaeozoic Fossils*, III, Pts. 1 and 2.

[2] Steidtmann, *loc. cit.*

on microscopical examination to contain very numerous oval yellow bodies, which are interpreted by White[1] to be unicellular gelosic algae, probably comparable to the living Protococcales. The precipitation of the well-known lead and zinc deposits of this formation is attributed by Bain[2] to the reducing action of the hydrocarbons, and probably to hydrogen sulphide, resulting from the partial decomposition of the algae. Whether in the Manitoba limestones the mottling may be accounted for in part by unicellular algae settling in local depressions on the sea floor—caused for instance by the burrowings of annelids or other animals in the silt—the writer is not prepared to say. After reviewing, however, the hypotheses which may be advanced to account for a phenomenon the origin of which it is difficult indeed precisely to define, he is compelled to conclude that the evidence is strongly in favor of the theory that the decomposition of algae has been primarily responsible for the local dolomitization which is so marked a feature of these limestones.

SUMMARY

The irregular mottling which is a characteristic feature of two horizons of the Ordovician limestones in Manitoba is due to the presence of certain dolomitic areas in the limestone. The color contrast is caused by hematite and limonite filling the interstices between the dolomite crystals, rendering the affected areas much darker than the non-dolomitic.

The apparently brecciated structure is not truly clastic. The darker areas have been dolomitized *in situ* by Mg-bearing waters, working from the center outward.

Chemical analyses show that the iron salts have been carried in the waters which affected the transformation, and the iron minerals are not, as might be supposed from microscopical investigation, the result of the oxidation, when recrystallization took place, of ferrous carbonate held isomorphously in the calcitic material of the limestone.

The evidence in the field and laboratory is sufficiently convincing to lead one to conclude that the dolomitization is not a subse-

[1] *Wisconsin Geol. and Nat. Hist. Soc.*, XIX, 26.

[2] *Ibid.*, 142.

quent phenomenon—due to the percolation of Mg-bearing waters from above through considerable thicknesses of limestone along lines of weakness, but took place as a practically contemporaneous process with the formation of the limestone, in the upper layers of the calcareous ooze of the sea bottom.

A limestone may undergo uniform dolomitization when the percentage of Mg ions in the sea water affecting it is much smaller than the chemical equations usually taken to represent the process would demand. The percentage of Mg ions in the seas in which the Lower and Upper Mottled limestones in Manitoba were laid down was probably considerably higher than that in the sea today, but lower than that necessary to cause dolomitization such as the darker areas have undergone.

Under such conditions three factors would tend to produce local dolomitization: (1) local rise in temperature, (2) presence of aragonite in the calcareous ooze, (3) a greater percentage of Mg ions in the water permeating certain parts of the hardening ooze. The last factor is the preponderating one in the area under investigation.

Three suggestions are considered as possible explanations of the irregular dolomitization: (1) sea water included in the shells, replacing the decomposed softer parts of gasteropods, etc., has in time affected the surrounding rock; (2) the castings of annelids have become dolomitized in preference to the surrounding rock; (3) the limestone immediately surrounding decomposing algae has been dolomitized, the magnesium salts liberated from the algae being sufficient to raise the percentage of Mg ions in the sea water so far that recrystallization could take place.

The writer considers the third suggestion that which best explains the facts of the case. How far the effect is to be attributed to fucoids, and how far to unicellular algae of the plankton, one cannot definitely ascertain; but fucoids probably played by far the main part in contributing the necessary magnesian salts.